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Patentanmeldung Nr. Patent application No. Demande de brevet n°

02079697.5

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Flexible device and method of manufacturing the same

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Flexible device and method of manufacturing the same

The invention relates to a flexible monolithic electronic device provided with:

- a substrate of insulating material having a first and an opposed second side, which substrate is provided with a first aperture extending from the first to the second side;
- an active layer of a semiconductor material at the first side of the substrate, in and on which active layer at least one switching element is defined, which element is provided with a first electrode in the active layer; and
- a flexible coating acting as a protective cover for the at least one switching element.

The invention also relates to an apparatus and a label comprising such flexible device.

The invention further relates to a method of manufacturing a flexible monolithic electronic device comprising a plurality of switching elements, comprising the steps of:

- providing a substrate provided with a first and an opposed second side, at which first side an active layer of a semiconductor material is present, in and on which active layer switching elements are provided, first electrodes of the switching elements being present in the active layer,
- removing the active layer partially, such that a functional entity comprising a plurality of the switching elements are present on at least one island;
- applying a flexible coating at the first side of the substrate, therewith covering the at least one island;
- temporarily adhering a carrier substrate at the first side of the substrate;
- removing the substrate from the second side including a wet-chemical etching step by an etchant, providing a functional layer at the second side that is connected to at least one first electrode through an aperture in an insulating layer.

Such a device and such a method are described in the non-prepublished application EP02100445.2 (PHDE010137). Herein, a method is described in which the switching elements are integrated circuit elements that constitute an integrated circuit. The substrate is a silicon-on-insulator substrate in particular, having a base layer of a semiconductor material, an oxide layer and an active layer of silicon. After the provision of

the coating and after a suitable pre-treatment with an adhesion agent, the carrier substrate of glass is adhered by means of glue. The substrate is then thinned so as to remove the base layer by means of wet chemical etching in a bath of an alkalic etchant like concentrated KOH. The oxidic layer acts herein as an etch stop layer, and may be removed thereafter. The exposed rear side of the integrated circuit elements may then be provided with an additional metallization level with bond pads. The carrier substrate is thereafter removed in that the device is peeled off from the substrate or vice versa.

It is a first object of the invention to provide a device of the kind mentioned in the opening paragraph with more functionality.

It is a second object of the invention to provide a method of the kind mentioned in the opening paragraph with which the device of the invention can be advantageously manufactured.

The first object is realized in that a functional layer being present at the second side of the substrate and being connected to the first electrode through the first aperture in the substrate. With the term 'functional layer' a layer is meant that extends over a substantial part of the substrate area and which fulfills in the device, alone or in combination with the switching elements, a specific function. Examples include electro-optical layers, conductive layers in which antennas are defined, high-K dielectric layers, such as ferroelectric layers for capacitors, layers for sensor applications, such as adhesion layers comprising antibodies for the adhesion of peptides, proteins or other biological material

The integration of such functional layer in the device is particularly important for very flexible and preferably rollable devices, in the flexibility acts as a burden for assembly. Even if a flexfoil can be suitably attached to bond pads, it is generally desired to use such flexfoil for power distribution only and if necessary for signal transfer. Any further elements however should be integrated.

In a preferred embodiment of the device, the functional layer is an electro-optical layer, which electro-optical layer constitutes with a switching element a display pixel. It is due to the provision of the electro-optical layer at the second side of the substrate that a rollable display can be made. Such rollable display is meant for use in combination with a mobile apparatus such as a mobile phone. Such a display cartridge is for instance described in the non-prepublished application EP02079131.5 (PHNL020942).

Electro-optical layers that are suitable for use in the invention include liquid-crystalline layers, organic, polymeric or inorganic electroluminescent layers as well as

electrophoretic layers. Particularly electrophoretic layers are preferred, since these provide a good contrast.

A technique for manufacturing a flexible display is per se known as SUFTLA®. It is disclosed in S. Utsunomiya et al. 'Flexible TFT-LEPD transferred onto plastic substrate using surface free technology by laser ablation/annealing' that was published in the Conference reports of Eurodisplay 2002, p.79-82. The flexible display of this technology is manufactured by provision thin film transistors on a glass substrate with a sacrificial amorphous silicon layer. Hereafter, the glass substrate is replaced by a plastic substrate, and the electro-optical layer is provided at the first side of the substrate. As can be seen from Fig. 4 of the paper, the resulting display is flexible in so far that it can be bended. However, it is by no means rollable as a foil. This is due, according to the inventors, to the fact that the source and drain electrodes of the transistors are provided with metallisations, one of which is again interconnected to the pixel electrode. A relatively thick of insulating material is therein needed to cover the transistors and to act as substrate for the pixel electrode. In the device of the invention, the second side of the substrate is in principle completely planar. Hence, neither a metallisation for the source and drain electrodes, nor an insulating layer of sufficient thickness to cover the transistor is needed.

It is suitable, for instance for an electro-optical layer of liquid crystalline material or of electroluminescent material, that a further electrode layer as counterelectrode is present. Also other layers known to the skilled person in the specific display types can be present if desired, such as a hole injection layer comprising poly(3,4-ethylenedioxythiophene) in the case of organic electroluminescent devices. Also, a further protective layer may be present adjacent to the further electrode layer.

In a further embodiment an electrically conductive layer is present between the active layer and the functional layer, in which conductive layer a pixel electrode is defined. Although the pixel electrode may be defined in the active layer, which is of course suitably and in known manner provided with dopant atoms to be electrically conductive in the area of the electrodes, it is preferred to provide it as a separate layer. This allows an optimal use of available space and enlarges the freedom of choice with respect to the substrate. Otherwise, the substrate needs to be relatively thin in order to have a substantially planar surface for the electro-optical layer. Further on, the capacity between the pixel electrode and metal lines present in interconnect layers in order to drive the gate electrode of the transistor can become too high in that case.

In an even further embodiment the display pixel comprises a capacitor with a first and a second electrode and a dielectric, which first electrode is present in the electrically conductive layer and which second electrode is defined in the active layer, the substrate acting as the dielectric. For displays which are voltage driven, such as a active matrix liquid-crystalline display, it is necessary to include a capacitor in each pixel. This capacitor can be advantageously integrated, when the first electrode is provided in the electrically conductive layer.

It is herewith preferred, that the substrate is provided with a high-K area and with a low-K area, which high-K area acts as the dielectric of the capacitor. This embodiment minimizes parasitic capacity between the electrically conductive layer and the active layer, while the capacitance density can be sufficiently high at the same time. This embodiment can be suitably made in that a provisional substrate, for instance of glass, or of silicon-on-insulator is first removed so that only the active layer is left. Then various layers can be provided and photolithographically patterned and etched. Suitable materials for the low-K area include SiLk, polyimide, benzocyclobutene, silicon oxide, organically modified silica and hydrogen and methylsilsesquioxane. Suitable materials for the high-K area include silicon nitride and ferroelectronic oxides with perovskite structures, that may be provided with sol-gel processing.

In a further embodiment of the display, the switching element is part of an array of switching elements present in and on the active layer, which array is driven by a driving circuit comprising an integrated circuit of circuit elements present in and on the active layer. As the connection of the flexible device to external parts is undesired, it is highly preferred to include any driver circuit in the device itself. This is very well possible, in that the active layer can be of high-quality monocrystalline or polycrystalline silicon, that is completely suitable for driver electronics.

In another embodiment of the invention the functional layer is a electrically conductive layer in which an antenna is defined and that a plurality of interconnected switching elements is provided constituting an integrated circuit. The antenna of this embodiment allows contactless communication between the integrated circuit and a reader. This communication includes the transfer of signals, but may include the transmission of power as well. Such antenna is suitable for low and moderate frequencies. For very high frequencies and short distances, i.e. above 2 GHz, an antenna may be included in the circuit. The antenna can be suitably made in that the substrate acts as a mask for depositing a seed layer, and subsequent electroplating. Also a barrier layer may be provided if desired.

The substrate of device of the invention may contain an oxide or any other insulating layer. If it is an oxide, this may be deposited after removal of a provisional substrate. Alternatively, a substrate with a buried oxide layer can be used and the buried oxide is not removal but patterned. Particularly in the case of a substrate with an oxide layer, it is preferred that the coating is provided with an oxide layer as well. It has been found that this counteracts uncontrollable curling of the device.

The coating of the device of the invention typically has a thickness in the order of 1 to 50 μm, preferably at 2-5 μm. It comprises an organic material by preference in view of the excellent flexibility of such materials. Suitable materials include among others epoxide, phenol, melamine, polyester, silicone resin or a polymer or copolymer hereof or a blend with other polymers, and may be reinforced with fibers, pigments, fillers, glass or metal. High-grade products which are still stable at higher temperatures that may be necessary in view of operating conditions or the provision of suitable materials at the second side of the substrate, are for instance based on polyimide resins, polycarbonate resins, fluorocarbon resins or polysulphon resins. Further information relating to the choice of the polymer can be found in the above mentioned non-prepublished application EP02100445.2 (PHDE010137).

The device of the invention can be suitably sold as part of a label and be used in combination with any apparatus, Suitable use for the embodiment with the antenna is in the area of identification and security. Suitable use for the display includes such identification and security issues, but may also be used for information purposes, as part of documents on paper for instance. For this purposes, it is not only advantageous that a driver circuit is present, but also that an antenna is present for contactless communication of power and signals.

The object to provide an improved method of the kind described in the opening paragraph is realized in that the applied coating of an organic material is provided with protection areas at side faces of the coating; and that the removal of the substrate includes a wet-chemical etching step by an etchant, to which etchant the coating is protected through the protection areas. In experiments done, it was found that the coating may be prone to swelling as a result of the interaction with the etchant, particularly with a strong base etchant as KOH. This swelling is not only detrimental for the visual appearance. It is also problematic for the provision of layers at the second, rear side of the substrate. Due to the swelling, the substrate is not planar enough, and layers cannot be provided in sufficient

resolution. In the method of the invention, this problem is solved through the definition of protection areas at the side faces of the coating, where it is in contact with the etchant during immersion in a bath thereof.

In a preferred embodiment hereof the organic material is applied according to a desired pattern, such that it is absent at the protection areas and present at device areas. Thereafter, the protection areas are given a treatment with adhesion means, and the removal of the electronic device from the carrier substrate is substantially limited to the device areas. Due to the patterning a glue layer is present in the protection areas and it is well adhered to the substrate due to the treatment with adhesion means. Therewith it constitutes an adequate protection of the organic material against the etchant.

In order to counteract curling and to provide very good adhesion at the protection areas, an oxidic layer can be provided on top of the coating of organic material. This has the additional advantage that silane coupling agents can be used as adhesion means. Examples include 3-methacryloyloxypropyl trimethoxysilane and glycidyloxypropyl trimethoxysiliane. After application of the carrier substrate of glass, the hydroxyl groups of the glass and the methoxy groups of the silane react with each other with the release of methanol. Herewith, the silane is bonded covalently to the glass surface through Si-O-Si bonds.

The carrier substrate will be removed before the devices are used. This removal step can be done directly after manufacture of the devices. This has the advantage that the carrier substrate can be reused. However, the removal step of the carrier substrate may also be done by a customer, which is particularly useful if the devices contain integrated circuits for security or identification purposes. Before this removal, the individual devices can then be programmed so as to contain an identification code. Also the removal step may not be done before the devices are attached to another carrier substrate, that will not be used. Such substrate, for instance of paper can then be cut along lines, so as to obtain a series of flexible devices. Preferably, the removal of the carrier substrate is realized by means of cutting, for instance with a razor blade.

These and other aspects of the device and the method of the invention will be further explained and elucidated with reference to the figures, in which:

Fig. 1-6 show in diagrammatical cross-sectional view various steps in the method.

The figures are not drawn to scale and like reference number refer to like parts. The figures are examples only and by no means limiting for the scope of the invention.

Fig. 1 shows a substrate 10 with a first side 1 and a second side 2. The substrate 10 comprises an active layer 11, an oxidic layer 12 and a base layer 13. The substrate is in this case a silicon on insulator substrate in which both base layer 13 and active layer 11 comprise silicon. The active layer 11 is herein of monocrystalline silicon. However, the active layer 11 may be a polycrystalline or amorphous silicon layer as well that is processed on an oxidized silicon wafer. The oxidic layer 12 is then for instance provided with PECVD. Alternatively, the oxidic layer 12 may be a highly doped buried layer. Also, a glass substrate may be used as a base layer 13.

Non-shown switching elements are defined in the active layer 11 and on top thereof. The switching elements are transistors of CMOS or TFT type, but may also be Micro-ElectroMechanical System (MEMS) switches or pindiodes. Further elements such as diodes, Schottky diodes, bipolar transistors, capacitors, resistors, optoelectrical elements and others may be present as well. They are interconnected according to a desired circuit pattern, that is known per se to the skilled person. Due to the use of an active layer 11 of a semiconductor material, preferably silicon, but possibly any III-V semiconductor material, a conventional circuit pattern can be used. To manufacture the switching and other elements, processes are carried out at or in the vicinity of the active layer 11. These processes include for instance oxidation steps, photolithography steps, selective etching steps and intermediate doping steps such as diffusion or ion implantation, all known per se. In case of thin film or CMOS transistors, source and drain electrodes as well as an intermediate channel are provided in the active layer, that is covered by a gate oxide layer and a gate electrode of polycrystalline silicon, a metal, a silicide. Additional metal layers for interconnection purposes can be provided. However, it is preferred to keep the number of layers limited. Hereinafter, or with various steps in between, superfluous regions of the active layer 11 and any layer on top of it are removed by wet-chemical or dry etching so as to obtain at least one island-like structure

Fig. 2 shows the result, after that the coating 3 is provided. The island-like structure is covered with a flexible coating, preferably a polymer. Preferably, the layer is provided by spin coating, spraying or the formation of a film, and is subsequently cured. The adhesion of the coating 3 to the active layer 11 and the stack of layers on top of that is enhanced in that first a cleaning step with fuming HNO_3 is done and thereafter it is treated

with a suitable primer. Then a polyamide resin coating 3 is formed in that a precursor of the polyimide is applied. After spincoating a solution of this material onto the wafer, the solvent is evaporated at 125 °C. Thereafter, a heating step at 200 °C is done to activate the primer. Then a photoresist 4 such as HPR504 is applied and exposed. The exposure results therein, that the photoresist 4 is present at the device area 21 and absent at the protection areas 22

Fig. 3 shows the result after some further steps. First, the coating is patterned through the photoresist mask 4. The patterning of the coating is realized with conventional developer solutions such as cyclopentanon. Then, the resist is stripped in a mixture of aceton and isopropanol. Hereafter, the coating 3 is cured at 300-400 °C. Finally, a 0,5 μm thick layer 5 of PECVD oxide is deposited at about 300 °C.

Fig. 4 shows the result after that the substrate 10 has been temporarily attached to a carrier substrate 30, and the substrate 10 has been thinned. Hereto, the protection areas 22 are treated with adhesion means, in this case a silane coupling agent. This treatment is done in a so-called "edge beat removal" fashion. Alternatively, the protection areas 22 are dipped into a solution of this silane primer. Next, a glue 31 and the carrier substrate 30 are provided. The thinning of the substrate is done in two steps, in the first of which the base layer 13 is grinded and thereafter it is etched with a KOH solution. Herein the oxidic layer 12 acts as an etch-stop layer.

Fig. 5 shows the result after that apertures 14 are provided in the oxidic layer 12. This is done in that a photoresist is applied on the oxidic layer 12 and patterned. The oxidic layer is then patterned. Hereafter, metal is provided in the apertures 14. This metal deposition includes a first step of depositing a barrier layer of $Ti_{0.9}W_{0.1}$ to onto which Al is deposited as usually. Alternatively, Cu can be deposited with electroplating.

Fig. 6 shows the result after that the flexible device 100 is removed from the carrier substrate 30. This is done by cutting through the oxidic layer 5 with a razor blade. Although the flexible device 100 is shown here as one device, it will be understood that this includes a plurality of devices 100. These may be separated afterwards. Also the separation step may be done by the customer.

Summarizing, the rollable device of the invention comprises a substrate of insulating material with apertures extending from a first to a second side. At the first side switching elements are present, as well as interconnect lines and the like, which is covered by a coating of organic material. At the second side a functional layer is present. Examples of such functional layers include capacitors, antennas and particularly electro-optical layers. Therewith a rollable display is obtained, that may include an antenna and a driver circuit.

CLAIMS:

1. A flexible monolithic electronic device provided with
- a substrate of insulating material having a first and an opposed second side, which substrate is provided with a first aperture extending from the first to the second side;
- an active layer of a semiconductor material at the first side of the substrate, in and on which active layer at least one switching element is defined, which element is provided with a first electrode in the active layer;
- a flexible coating acting as a protective cover for the at least one switching element,
- a functional layer being present at the second side of the substrate and being connected to the first electrode through the first aperture in the substrate.

2. A flexible electronic device as claimed in Claim 1, characterized in that the functional layer is an electro-optical layer, which electro-optical layer constitutes with a switching element a display pixel.

3. A flexible electronic device as claimed in Claim 2, characterized in that an electrically conductive layer is present between the active layer and the functional layer, in which conductive layer a pixel electrode is defined.

4. A flexible electronic device as claimed in Claim 3, characterized in that the display pixel comprises a capacitor with a first and a second electrode and a dielectric, which first electrode is present in the electrically conductive layer and which second electrode is defined in the active layer, the substrate acting as the dielectric.

5. A flexible electronic device as claimed in Claim 4, characterized in that the substrate is provided with a high-K area and with a low-K area, which high-K area acts as the dielectric of the capacitor.

6. A flexible electronic device as claimed in Claim 2, characterized in that the switching element is part of an array of switching elements present in and on the active layer,

which array is driven by a driving circuit comprising an integrated circuit of circuit elements present in and on the active layer.

7. A flexible electronic device as claimed in Claim 1, characterized in that the functional layer is a electrically conductive layer in which an antenna is defined and that a plurality of interconnected switching elements is provided constituting an integrated circuit.

8. An apparatus comprising a flexible device according to any of the Claims 1-7.

9. A label comprising a carrier and the flexible device according to any of the Claims 1-7, which is provided with a glue layer and therewith reversibly/removably attached to the carrier.

10. A rollable cartridge comprising the display according to any of the Claims 2-6.

11. A method of manufacturing a flexible monolithic electronic device comprising a plurality of switching elements, comprising the steps of:

- providing a substrate provided with a first and an opposed second side, at which first side an active layer of a semiconductor material is present, in and on which active layer switching elements are provided, first electrodes of the switching elements being present in the active layer,
- removing the active layer partially, such that a functional entity comprising a plurality of the switching elements are present on at least one island;
- applying a coating of a flexible material at the first side of the substrate, therewith covering the at least one island; the coating being provided with protection areas at side faces of the coating;
- temporarily adhering a carrier substrate at the first side of the substrate;
- removing the substrate from the second side including a wet-chemical etching step by an etchant, to which etchant the coating is protected through the protection areas; and
- providing a functional layer at the second side that is connected to at least one first electrode through an aperture in an insulating layer.

12. A method as claimed in Claim 11, characterized in that:

- the organic material is applied according to a desired pattern, such that it is absent at the protection areas and present at device areas,
- the protection areas are given a treatment with adhesion means, and
- the removal of the electronic device from the carrier substrate is substantially limited to the device areas.

ABSTRACT:

The rollable device of the invention comprises a substrate of insulating material with apertures extending from a first to a second side. At the first side switching elements are present, as well as interconnect lines and the like, which is covered by a coating of organic material. At the second side a functional layer is present. Examples of such functional layers include capacitors, antennas and particularly electro-optical layers. Therewith a rollable display is obtained, that may include an antenna and a driver circuit.

Fig. 6

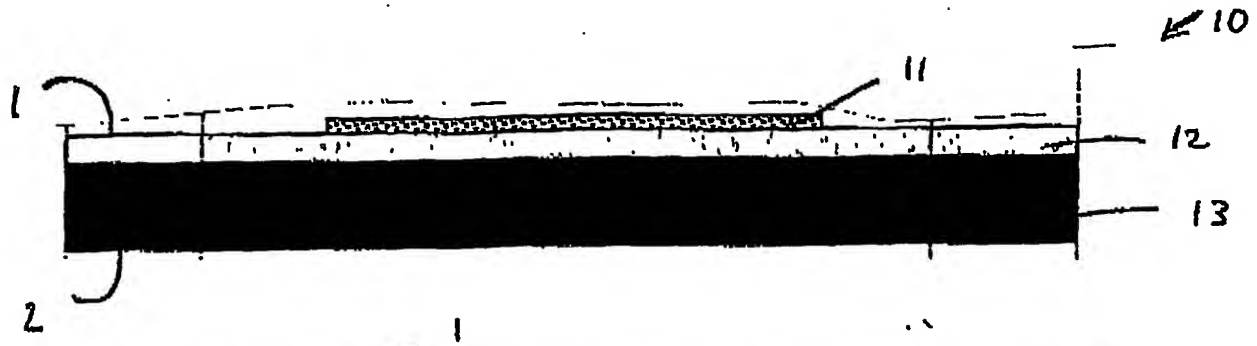

Fig 1

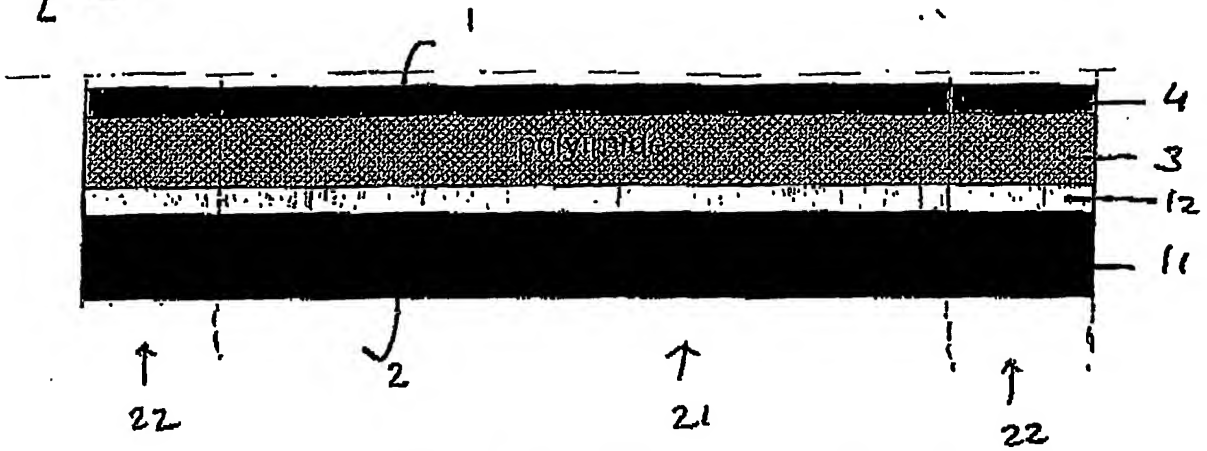

Fig 2

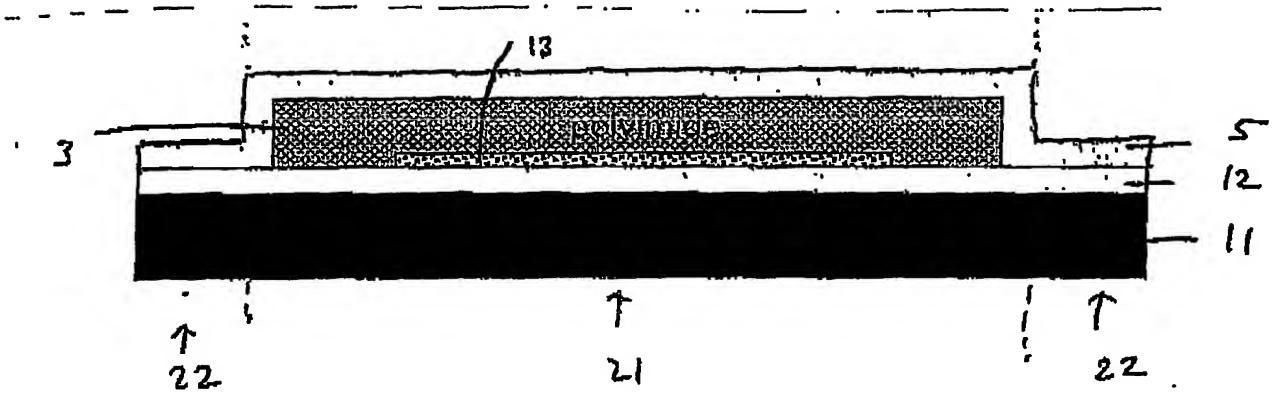

Fig 3

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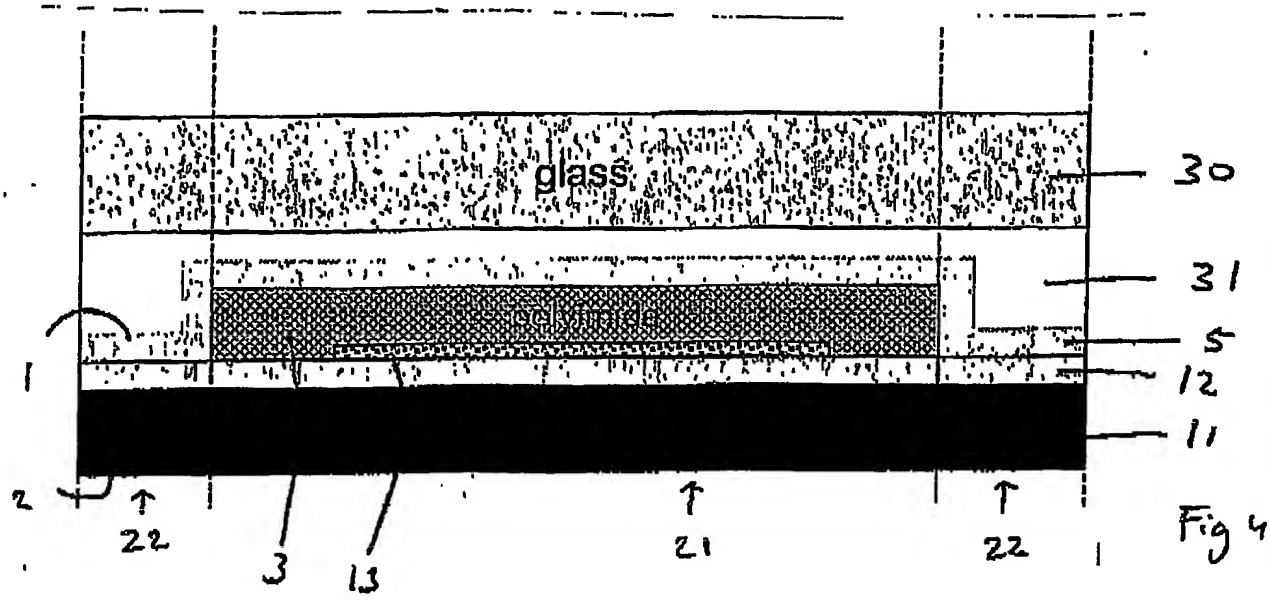

Fig 4

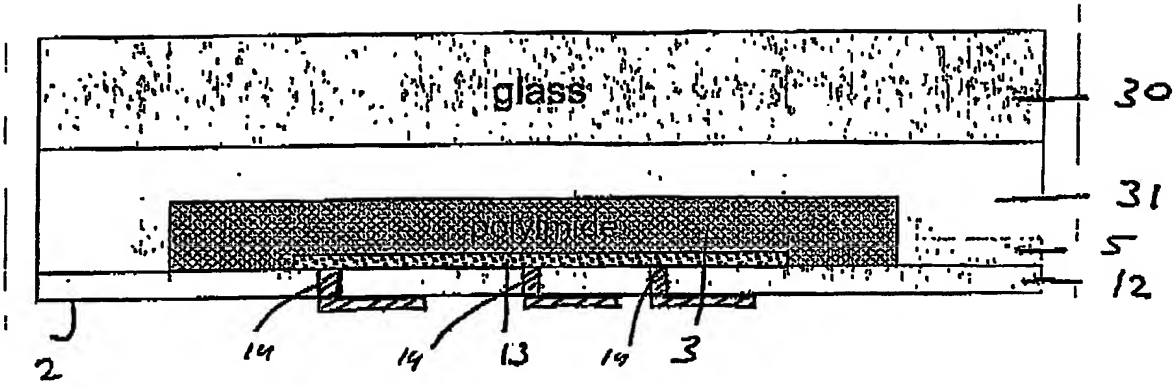

Fig 5.

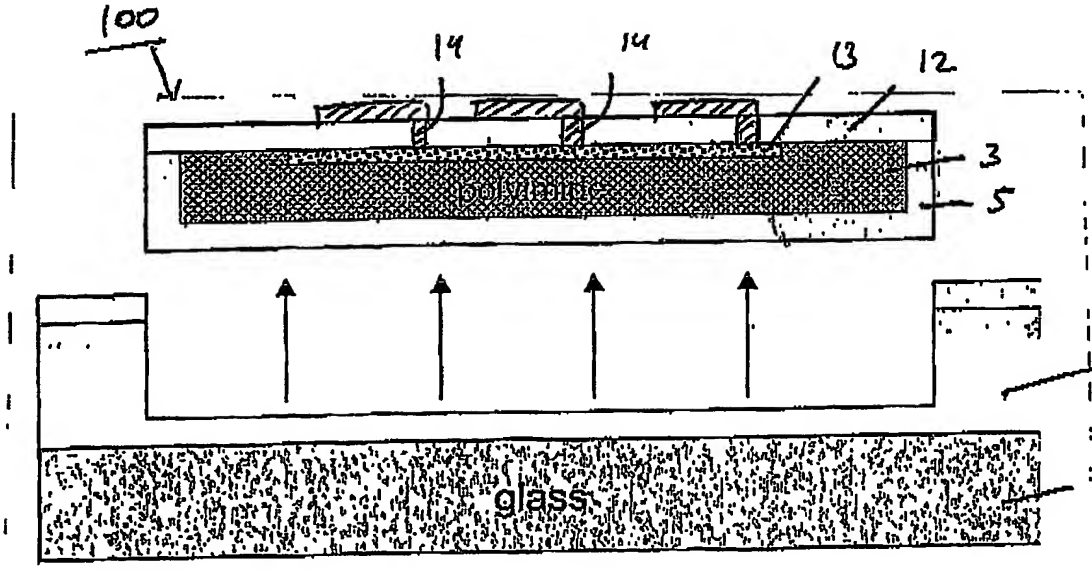

Fig. 6

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